

HYDROGEOLOGIC INFORMATION IN THE GREAT LAKES BASIN, UNITED STATES,  
AND APPLICATION OF A GEOGRAPHIC INFORMATION SYSTEM TO PUBLIC-  
SUPPLY WELLS AND HAZARDOUS-WASTE SITES

by Kelly L. Warner, John D. Earle, and Marvin G. Sherrill

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Dallas L. Peck, Director

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For additional information  
write to:

District Chief  
U.S. Geological Survey  
4th Floor  
102 E. Main Street  
Urbana, IL 61801

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## CONVERSION FACTORS

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<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
square mile ( $\text{mi}^2$ )	2.590	square kilometer
gallon per day per square mile ( $\text{gal/d}/\text{mi}^2$ )	0.00146	cubic meter per day per square kilometer

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ABSTRACT

A computerized data base has been established to facilitate analysis and interpretation of potential for ground-water contamination in the Great Lakes basin. The computerized data base is being used in conjunction with a geographic information system (GIS). Locations of public-supply wells were obtained from Federal and State agencies and stored in the system. Well locations are displayed using the Albers equal-area projection. A GIS was used to create a map of public-supply wells and a map of combined waste sites and public-supply wells.

A comprehensive bibliography of 1,114 references, published during the period 1960-86, pertaining to hydrogeologic studies in the Great Lakes basin and geographic information systems, has been compiled using a relational data-base program. Where possible, references are indexed by State and county to assist in determining areas where additional study is necessary.

INTRODUCTION

In 1978, the U.S. and Canada signed a renewed Great Lakes Water Quality Agreement that calls for identifying emerging water-quality problems in the Great Lakes basin. The agreement does not specify monitoring the chemical quality of the ground water, but, in 1982, the Science Advisory Board of the International Joint Commission recommended that "ground-water resources of the Great Lakes System be studied to determine potential contamination routes via this source and to establish mitigative measures" (Swain, 1985). Subsequent reports written for the Commission by Swain (1985) for the U.S., and by Gillham (1985) for Canada, document conditions and locations throughout the Great Lakes basin where ground water is susceptible to contamination.

Swain (1985) found conditions favorable in the U.S. for the transport of contaminants to the Great Lakes by the discharge of ground water to the lakes. Permeable glacial deposits and fractured bedrock in the Great Lakes basin allow rapid infiltration and movement of water and contaminants to the water table, into deeper aquifers, and eventually to streams and lakes. Swain (1985, p. 18) states that "the greatest concentration of hazardous-waste sites are in areas adjacent to the lakes near Chicago, Cleveland, and the Niagara River area."

In 1984, the Groundwater Contamination Task Force was established by the Science Advisory Board to construct a proposal outlining the strategy needed to determine the extent and potential effects of ground-water contamination on the Great Lakes. That proposal recommends that all existing reports, data, and maps for the basin be compiled. The maps would consist of, but not be limited to, the following: composition of surficial materials and depth to bedrock, bedrock geology, permeability of surficial materials, ground-water-flow characteristics, aquifer use, land use, and locations of point sources of ground-water and surface-water contamination.

In 1987, the U.S. Geological Survey (USGS) initiated a project to achieve two of the goals stated above. The work effort involved the listing of existing reports, theses, dissertations, and ongoing activities; and the development of maps locating the potential point sources of ground-water contamination in the eight States adjacent to the Great Lakes.

#### Purpose and Scope

This report describes the development of a bibliographic listing and the potential sources of ground-water contamination in the Great Lakes basin, gathered from academic researchers and State and Federal agencies in the eight States adjacent to the Great Lakes. Basinwide maps were developed showing the location of public-supply wells and waste sites. The sites include all known contaminated sites as of 1986.

#### Description of Study Area

The Great Lakes basin, which contains the largest volume of freshwater in the world, has one of the largest concentrations of population and industry in the U.S. Nearly half of the basin's land area is underlain by aquifers that have the potential to yield more than 250,000 (gal/d)/mi<sup>2</sup> (Great Lakes Basin Commission, 1975c, p. 7). Throughout most of the Great Lakes basin, shallow ground-water divides coincide with surface-water divides; therefore, in this report, the perimeter of the Great Lakes basin in the U.S., the study area, is defined by the surface-water drainage divides.

The Great Lakes basin consists of the drainage basins of the five Great Lakes--Erie, Huron, Michigan, Ontario and Superior--and has a combined land and water area of 298,800 mi<sup>2</sup>. In the U.S., these drainage basins contain all or part of 8 States--Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania and Wisconsin--and all or part of 207 counties in these States (fig. 1). The combined land and water area of the Great Lakes basin in the U.S. is 178,400 mi<sup>2</sup>, or 59.7 percent of the total basin.

Population density in the Great Lakes basin is four times that of the national average, making the basin the most densely inhabited inland region in the U.S. (Great Lakes Basin Commission, 1976a, p. 18). Approximately 31 million people live in the U.S. part of the Great Lakes basin. This population has

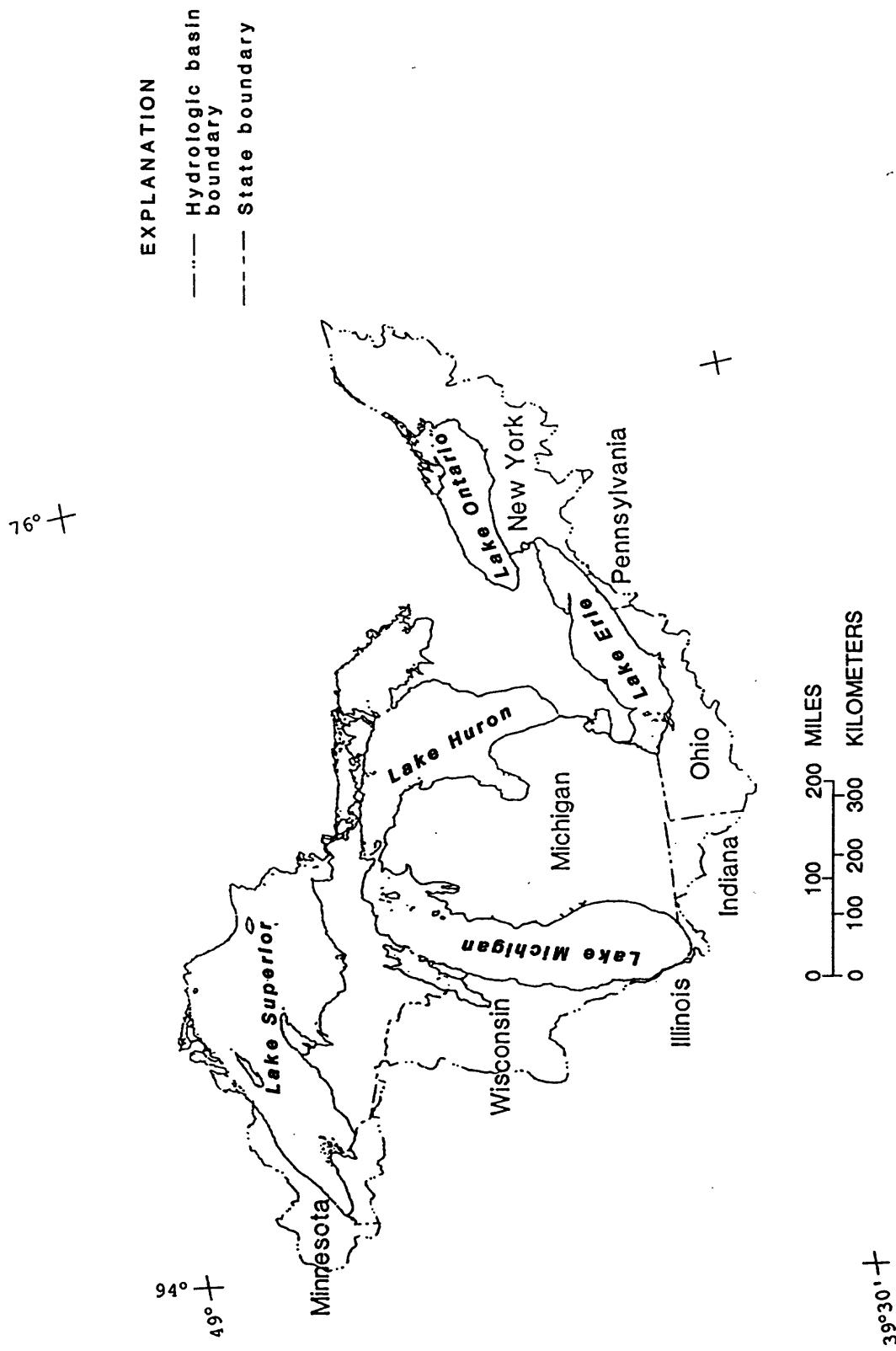


Figure 1.--Location of the Great Lakes basin in the United States.

stayed more or less constant since 1980 (U.S. Department of Commerce, 1986). Illinois and Wisconsin are the only States whose population increased since 1980. Twenty of the 207 counties in the basin contain 50 percent of the population. Two counties--Cook County, Illinois, and Cuyahoga County, Ohio--have more than 1 million inhabitants. The basin also contains 20 percent of the manufacturing value in the U.S. (Great Lakes Basin Commission, 1975a, p. 6).

Determination of direct- and indirect-ground-water flow in the basin is essential to understanding the total ground-water inputs to the Great Lakes. Nearly half of the basin's land area is underlain by aquifers that have the potential to yield more than 250,000 (gal/d)/mi<sup>2</sup> (Great Lakes Basin Commission, 1975c, p. 7). The direct-ground-water flow to the Great Lakes is commonly assumed to be the amount of water input that is not accounted for by surface-water flow and precipitation. Direct-ground-water flow to the Lakes has not been measured for the basin. Indirect flow is the ground water that flows to streams that discharge to the Lakes. Thus, the effect of ground water on the water budget, and ultimately the water quality of the Great Lakes, is not fully understood.

Although productive aquifers are found throughout the basin, ground water is often ignored in studies of the water budget of the Great Lakes. Taylor and Cherkauer (1984) estimated that ground-water contributions to the Lake Michigan water budget can be as high as 5 to 10 percent. This can have a noticeable effect on the Lake's chemistry, because ground water generally carries much higher concentrations of dissolved constituents than does rain water or surface water.

#### Acknowledgments

This project was made possible through the support of the International Joint Commission, and funding by the U.S. State Department and U.S. Geological Survey, Office of Water Data Coordination. Thanks are given to the various State agencies that provided public-supply-well locations. Articles and references from universities, research institutes, and laboratories in the Great Lakes basin are greatly appreciated.

#### HYDROGEOLOGIC INFORMATION

A bibliography of 1,114 references pertaining to the hydrogeology of the Great Lakes basin in the U.S. was compiled in a relational data-base system. The references were collected from many sources. Computerized bibliographic searches were completed on several subjects, including ground water, water quality, contamination sources, geology, and land use. An earth-science data base, GeoRef (Geological References), produced by the American Geological Institute, was the primary data base searched. Letters were sent to various research institutions in the Great Lakes basin requesting lists of their publications, on-going research, and reprints. The USGS water-use specialists in each of the Great Lakes States provided supplementary information for the bibliography. The criteria used for selecting documents was their relevance to the above list of subjects.

The bibliographic data base was arranged alphabetically by author, and each reference was given a unique number. The unique numbers are used to index the references to various subjects. The subject terms used to index each reference were taken from "GEOREF Thesaurus and Guide to Indexing" (Riley, 1981) and "Water Resources Thesaurus" (U.S. Department of the Interior, 1980). Each reference was coded by State and county if the information was readily accessible. The data base can be searched by author, subject, State, county, and year. The bibliography is in a relational data base that may be accessed from a geographic information system (GIS).

#### APPLICATION OF A GEOGRAPHIC INFORMATION SYSTEM

A GIS was used to generate digital maps of public-supply wells and hazardous-waste sites. The GIS is used to manage digital data related to each public-supply well or hazardous-waste site. The data was collected from various sources.

##### Public-Supply Wells

Site-specific data for public-supply wells (henceforth referred to as wells) were retrieved from the USGS State Water-Use Data System (SWUDS), the Ground-Water Site Inventory (GWSI), and (or) from State agencies in 1987. The SWUDS and GWSI are USGS-maintained data-storage and retrieval systems that contain ground-water information from local, State, Federal, and private organizations. The SWUDS contains water-use data, and the GWSI contains aquifer characteristics and well data. Locations of 4,236 wells in 8 States are shown on plate 1--Illinois (13), Indiana (316), Michigan (2,939), Minnesota (46), New York (245), Ohio (322), Pennsylvania (36), and Wisconsin (319).

Obtaining well locations was the primary goal for compiling the public-supply-well map, but additional information was requested, including well owner, well identification number, State, county, latitude and longitude, hydrologic unit, aquifer; township, range, and section (TRS); and remarks. Remarks include total withdrawals for 1986 and comments regarding the status or accuracy of the well location. Data on aquifer characteristics were not available for most older wells.

There are no consistent guidelines for collecting and storing well information among the States in the Great Lakes basin. Discrepancies concerning definition of what constitutes a public-supply well and inconsistencies among data-collection programs cause disparities in the regional data base. For example, the large concentration of wells in the eastern part of the Upper Peninsula of Michigan results from the designation of fire department wells as public-supply wells. Snavely (1986) summarizes the water-use programs, including well data for the Great Lakes basin.

The information obtained on wells had to be manipulated for use in an ARC/INFO<sup>1</sup> GIS. Latitude and longitude coordinates or Universal Transverse Mercator (UTM) coordinates of wells were converted to Albers map coordinates in order to be consistent with other USGS GIS data bases. Location descriptions are given for wells in some States by township, range, section, and quarter-section coordinates. Latitude and longitude were obtained for these wells by manually plotting the points on 7-1/2-minute topographic quadrangle maps, then encoding the corresponding latitude and longitude into the system. The well locations were plotted in the center of the closest quarter section.

The source of data in each State determines the accuracy of the location information. Some agencies report site-specific information, but most previously published data were aggregated by county. State agencies use various legal or unique geographic coordinates that must be converted to latitude and longitude, UTM, State plane, or other coordinates that are readily input to ARC/INFO.

Most locations of wells in New York were provided by the New York Department of Public Health in latitude and longitude, but some latitudes and longitudes were determined from well locations plotted and digitized on paper maps. Half of the Minnesota wells were located from a well-tabulation form (Lee Trotta, U.S. Geological Survey, oral commun., 1987), and the latitudes and longitudes for the rest of the wells were derived by manually plotting well locations. In Michigan, 99 percent of the 2,939 wells were located only by street address provided by the Michigan Department of Public Health. The conversion of street address to latitude and longitude was accomplished for approximately 75 percent of the wells in Michigan by locating, and then digitizing, the wells on topographic maps. Wells in the Upper Peninsula had TRS information (1 percent of wells) that was manually plotted on 7-1/2-minute quadrangle maps; latitude and longitude were determined from these maps. The Michigan State University, Center for Remote Sensing, digitized most public-supply-well locations for the purpose of evaluating trends in nitrate contamination of ground water (Kittleson and Kruska, 1986). This information is in unique coordinates that could not be converted to ARC/INFO coordinates at the time of the writing of this report (Mike Badar, University of Michigan, oral commun., 1988).

Information for Illinois, Indiana, Ohio, Pennsylvania, and Wisconsin was readily available and needed only minor revisions to develop a location coverage in ARC/INFO. The Illinois State Water Survey located wells by TRS; each section further subdivided to locate the well within a 10-acre plot. These were manually converted to latitude and longitude. The Indiana Department of Natural Resources provided information in UTM coordinates. The Ohio Department of Natural Resources provided locations in latitude and longitude. The well locations in latitude and longitude for Pennsylvania and Wisconsin were provided by the USGS District offices.

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<sup>1</sup>Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

### Waste Sites

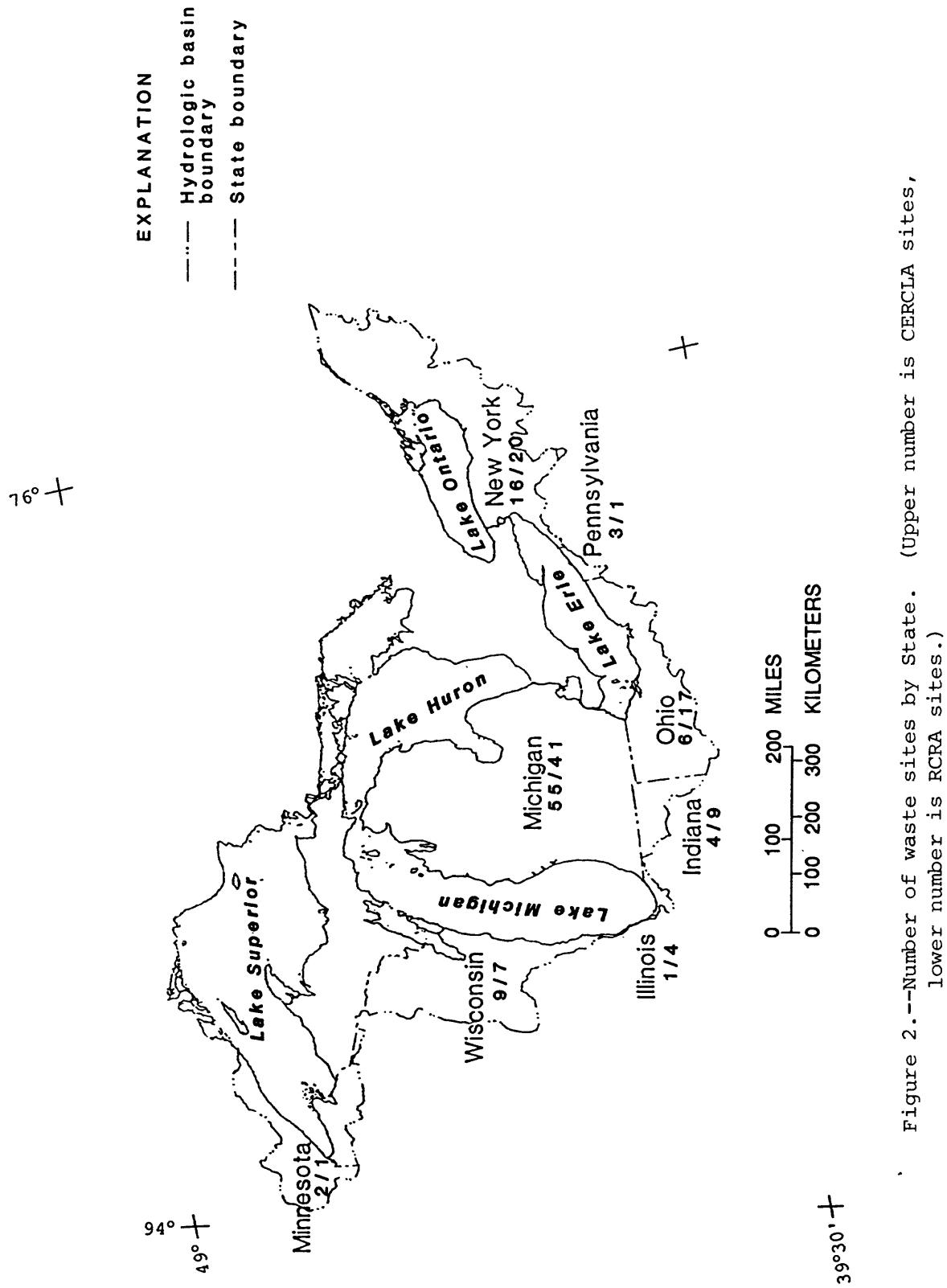
The waste sites include all known contaminated sites as of 1986 listed under the Resource Conservation and Recovery Act (RCRA) of 1976 and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980. The basin contained 196 waste sites in 1986 (pl. 2 and fig. 2) (U.S. Geological Survey, 1988b). Six attributes in the GIS are associated with each site.

Several problems were discovered in producing these maps by means of a GIS. The maps that were developed from existing information have several resolution problems. If no latitude and longitude were available for a site, latitude and longitude were computer generated by the centroid of the postal zone improvement program (ZIP) code. The latitude and longitude coordinates generated from the ZIP code correspond to the owners address, which is not always the same as the waste-site ZIP code. This is the only computerized information available. Care should be taken in using this map (pl. 2) for planning purposes because the locations of the waste sites are not field verified.

A second problem concerns the accuracy of determining the number of waste sites in a given area. One point may represent more than one site. This problem is most likely the result of computer-generated latitude and longitude that plot all sites with the same postal ZIP code at the center of the city. Resolution of density on the existing data base could be enhanced by searching for identical latitudes and longitudes and then using a unique symbol to represent site density.

Many institutions in the Great Lakes basin are using ARC/INFO to create and edit digital information. The ARC/INFO data base that the USGS established is based on existing national or regional digital data. There is a need to integrate existing digital data from a variety of sources and to edit all data bases for precision and applicability. By using ARC/INFO, very specific regional information can be accumulated and used in local studies or generalized for regional analysis. Documentation of digitized information and map-scale variability will determine the extent to which this information can be integrated.

There are many sources of digital data. Currently, the National Cartographic Information Center and the Information Systems Division of the USGS have two computerized information directories--the Spatial Digital Data Directory and the Earth Science Data Directory. These directories include references to GIS data bases and sources of information.



## SUMMARY

A bibliography of 1,114 references pertaining to the hydrogeology of the Great Lakes basin in the U.S. was compiled in a relational data-base system. These references span the period 1960-86. When information was available, the references were indexed by author, year, subject, State, and county. Regional information on aquifers and water quality is scarce.

A GIS was used for data management and for the display of locations of public-supply wells and waste sites. Public-supply-well information was collected from USGS water-data storage systems or from State agencies.

A map showing the proximity of public-supply wells to waste sites was developed using ARC/INFO. Waste sites include all known contaminated RCRA and CERCLA sites as of 1986. Problems involving accurate site locations of waste sites include location duplication and inaccurate extrapolation of latitude and longitude based on site address and postal ZIP code.

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**APPENDIX B--Index of Subjects**

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<u>Subject</u>	<u>Reference Numbers</u>						
Agriculture	000021	000022	000023	000033	000034	000052	000082
	000100	000118	000120	000216	000224	000364	000373
	000498	000524	000536	000725	000780	000862	000966
	000996	000999	001029	001055	001109		
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	000020	000024	000037	000041	000046	000050	000058
	000073	000074	000075	000076	000077	000087	000091
	000099	000105	000108	000109	000110	000111	000112
	000116	000120	000124	000125	000131	000133	000142
	000143	000150	000151	000152	000175	000180	000181
	000182	000184	000193	000194	000195	000196	000197
	000198	000199	000223	000238	000245	000251	000252
	000260	000263	000279	000303	000349	000378	000434
	000447	000451	000453	000477	000501	000509	000510
	000511	000513	000514	000524	000525	000536	000599
	000604	000605	000606	000611	000630	000631	000658
	000671	000677	000680	000682	000716	000720	000721
	000724	000729	000757	000788	000789	000792	000812
	000818	000826	000827	000829	000844	000849	000863
	000871	000880	000904	000909	000919	000930	000932
	000933	000954	000997	001003	001005	001018	001019
	001040	001052	001079	001104	001106	001114	
Base Flow	000005	000124	000751	001114			
Bedrock	000004	000009	000014	000015	000019	000025	000041
	000047	000099	000102	000112	000133	000143	000146
	000148	000150	000185	000223	000266	000286	000287
	000372	000381	000400	000401	000432	000434	000445
	000488	000555	000627	000664	000703	000710	000794
	000834	000839	000898	000926	000943	001022	001023
	001025	001026	001027	001065	001108		
Bibliography	000303	000326	000330	000353	000423	000428	000517
	000542	000543	000544	000545	000546	000547	000551
	000623	000784	000797	000803	000817	000921	001047
	001078	001112					
Carbonates	000073	000074	000110	000203	000493	000576	000658
	000681	000682	000683	000793	000863	000910	
Cartography	000097	000168	000297	000341	000481	000579	000612
	000845	000988	000991	000994	001055		

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	000068	000073	000082	000088	000100	000104	000106
	000109	000121	000122	000123	000125	000129	000144
	000151	000154	000169	000173	000174	000204	000206
	000210	000219	000234	000236	000263	000276	000285
	000305	000309	000312	000317	000318	000319	000346
	000366	000371	000403	000409	000418	000454	000455
	000458	000468	000473	000479	000480	000501	000502
	000521	000522	000524	000532	000539	000552	000560
	000564	000565	000566	000567	000569	000570	000571
	000608	000609	000610	000621	000629	000640	000641
	000670	000672	000674	000677	000685	000686	000687
	000704	000705	000715	000731	000736	000740	000749
	000750	000752	000754	000829	000849	000852	000856
	000858	000864	000870	000871	000872	000908	000916
	000924	000934	000948	000959	000963	000970	000971
	000987	000997	001001	001002	001021	001051	001086
	001088	001110					
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	000379	000489	000490	000613	000620	000818	000846
	000936	000997	001019	001063	001077	001104	
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	000086	000100	000109	000118	000121	000142	000173
	000174	000179	000181	000182	000219	000221	000234
	000240	000241	000242	000243	000245	000253	000258
	000259	000279	000284	000285	000290	000312	000313
	000316	000349	000424	000426	000435	000439	000458
	000467	000475	000476	000498	000501	000502	000510
	000522	000524	000539	000558	000560	000561	000597
	000608	000609	000670	000674	000687	000704	000705
	000709	000720	000736	000749	000752	000771	000783
	000786	000806	000808	000818	000849	000850	000852
	000855	000856	000861	000862	000863	000864	000869
	000891	000892	000893	000901	000906	000916	000918
	000922	000925	000931	000952	000959	000963	000964
	000966	000968	000972	000976	001002	001016	001043
	001050	001051	001064	001085	001086	001087	001090
Data	000003	000004	000012	000026	000034	000036	000037
	000044	000052	000060	000083	000084	000097	000121
	000140	000146	000154	000155	000168	000214	000216
	000225	000239	000251	000263	000271	000274	000282
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	000345	000375	000387	000388	000389	000390	000391
	000392	000393	000394	000395	000415	000428	000431
	000433	000444	000481	000523	000527	000542	000543
	000544	000546	000547	000551	000559	000612	000691
	000701	000714	000724	000784	000790	000796	000805
	000831	000841	000848	000849	000868	000889	000906
	000907	000941	000986	000988	000991	000994	000998
	001006	001107					

<b>Deposits</b>	000007	000030	000053	000056	000059	000094	000101
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	000507	000512	000534	000614	000633	000634	000662
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	000902	000946					
<b>Dewatering</b>	000211	000525	000557	001019			
<b>Discharge</b>	000014	000061	000074	000076	000091	000108	000112
	000116	000221	000519	000676	000677	000720	000724
	000801	001036					
<b>Dolomite</b>	000073	000074	000091	000111	000203	000352	000493
	000602	000658	000677	000680	000682	000812	000826
	000861	000863	000933				
<b>Drainage</b>	000021	000030	000033	000061	000247	000484	000579
	000714	000715	001018	001103			
<b>Drift</b>	000025	000094	000105	000108	000175	000367	000494
	000511	000512	000614	000664	000701	000735	000792
	000794	000806	000860	000870	001062		
<b>Economics</b>	000045	000147	000153	000169	000188	000216	000217
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	000484	000519	000721	000723	000792	000829	000852
	000872	000880	000902	001001	001020	001045	001113
<b>Engineering Geology</b>	000036	000115	000172	000253	000272	000280	000433
	000499	000549	000658	000695	000701	000702	000717
	000913	001005	001045	001095	001100		
<b>Environment</b>	000002	000007	000013	000030	000033	000047	000067
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	000495	000531	000554	000641	000678	000722	000735
	000799	000825	000850	000869	000935	000938	000960
	000973	000974	001000				
<b>Environmental Geology</b>	000003	000029	000033	000054	000065	000087	000097
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	000137	000147	000156	000169	000220	000236	000253
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	000631	000633	000638	000665	000674	000691	000701
	000702	000718	000720	000747	000748	000750	000809
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	000915	000941	000957	000976	000977	000988	000991
	001043	001045					

Erosion	000023	000052	000094	000097	000126	000205	000212
	000213	000302	000304	000519	000718	000819	000820
	000909	000999	001002	001017			
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	000061	000072	000074	000076	000091	000092	000102
	000103	000104	000105	000108	000113	000116	000121
	000125	000150	000172	000177	000187	000245	000278
	000337	000338	000339	000364	000378	000476	000477
	000484	000501	000509	000524	000531	000597	000602
	000631	000632	000660	000677	000690	000713	000721
	000728	000734	000740	000753	000754	000763	000766
	000767	000768	000769	000773	000777	000782	000788
	000789	000792	000806	000808	000818	000850	000852
	000860	000862	000863	000899	000909	000924	000929
	000931	001005	001013	001040	001065	001102	001104
Geochemistry	000019	000029	000051	000056	000069	000079	000220
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	000468	000508	000509	000630	000674	000720	000748
	000750	000823	000869	000870	000871	000888	000915
Geologic Hazard	000008	000280	001045				
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	000186	000188	000193	000194	000197	000198	000199
	000203	000208	000209	000232	000238	000246	000257
	000266	000272	000320	000321	000324	000333	000350
	000369	000370	000372	000376	000380	000385	000396
	000430	000456	000459	000484	000492	000501	000507
	000535	000542	000543	000544	000546	000554	000578
	000596	000600	000601	000614	000622	000623	000626
	000627	000628	000636	000637	000663	000679	000682
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	000798	000809	000833	000834	000839	000862	000875
	000876	000885	000904	000917	000920	000921	000930
	000939	000943	000949	001012	001013	001024	001070
	001076	001080	001095	001105	001114		
Geomorphology	000007	000028	000030	000037	000065	000093	000094
	000101	000117	000138	000141	000200	000231	000232
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	000579	000600	000601	000662	000673	000720	000722
	000734	000735	000795	000842	000900	000909	000958
	001062	001096	001103				

Geophysics	000014	000025	000035	000036	000044	000077	000089
	000099	000150	000199	000232	000238	000336	000342
	000367	000400	000401	000477	000509	000512	000579
	000720	000727	000929	000933	001095		
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	000191	000211	000214	000216	000239	000249	000269
	000270	000296	000297	000341	000379	000431	000433
	000481	000489	000490	000550	000612	000619	000805
	000832	000940	000941	000988	000991	001055	001063
Glacial Aquifer	000005	000009	000010	000041	000046	000078	000091
	000092	000099	000105	000106	000124	000131	000140
	000141	000142	000143	000144	000148	000149	000150
	000151	000170	000171	000181	000185	000193	000194
	000195	000196	000197	000198	000222	000279	000340
	000351	000354	000355	000358	000359	000360	000365
	000374	000434	000442	000449	000450	000460	000462
	000482	000486	000487	000491	000514	000517	000518
	000528	000532	000556	000596	000597	000599	000604
	000606	000616	000617	000618	000666	000667	000668
	000676	000688	000689	000690	000706	000710	000716
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	000843	000844	000850	000905	000932	001003	001030
	001031	001035	001036	001042	001078	001097	001108
Glacial Geology	000002	000007	000015	000017	000025	000028	000030
	000041	000047	000057	000059	000080	000093	000094
	000095	000099	000101	000105	000117	000128	000133
	000139	000176	000184	000188	000199	000200	000201
	000229	000230	000231	000232	000233	000237	000266
	000268	000333	000352	000369	000380	000384	000416
	000438	000456	000477	000484	000485	000494	000495
	000507	000511	000512	000531	000534	000553	000555
	000579	000614	000633	000634	000639	000662	000664
	000673	000722	000734	000735	000744	000763	000766
	000788	000789	000794	000795	000806	000812	000824
	000842	000847	000875	000900	000912	000923	000935
	001003	001058	001059	001060	001062	001098	001099
							001100

Ground Water	000006	000046	000060	000077	000099	000107	000112
	000133	000150	000152	000182	000184	000193	000194
	000195	000196	000197	000218	000223	000258	000263
	000276	000277	000278	000288	000343	000344	000349
	000350	000386	000392	000393	000397	000398	000402
	000404	000435	000443	000448	000457	000469	000500
	000501	000506	000524	000525	000527	000536	000540
	000675	000677	000692	000721	000737	000746	000804
	000810	000811	000813	000814	000815	000827	000833
	000849	000854	000860	000880	000897	000917	000918
	000947	000948	000949	000959	001003	001006	001007
	001010	001037	001048	001049	001089		
History	000093	000215	000230	000311	000380	000385	000456
	000707	001069	001098				
Hydrochemistry	000016	000019	000103	000129	000210	000276	000457
	001043						
Hydrogeology	000004	000006	000008	000009	000010	000011	000013
	000014	000017	000024	000026	000037	000039	000041
	000061	000065	000069	000073	000074	000075	000076
	000077	000086	000102	000103	000104	000105	000108
	000111	000112	000113	000134	000135	000136	000137
	000139	000152	000175	000178	000184	000185	000189
	000193	000194	000195	000196	000197	000198	000205
	000210	000214	000217	000220	000223	000235	000236
	000251	000253	000272	000273	000275	000293	000294
	000295	000296	000303	000336	000338	000345	000346
	000350	000360	000364	000368	000378	000382	000398
	000431	000441	000445	000446	000460	000477	000480
	000483	000509	000511	000535	000556	000557	000596
	000599	000604	000605	000606	000611	000618	000631
	000632	000640	000642	000671	000677	000700	000709
	000712	000713	000714	000716	000717	000718	000721
	000724	000727	000732	000740	000753	000754	000763
	000766	000778	000789	000792	000802	000812	000815
	000816	000818	000826	000851	000853	000859	000860
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	000872	000902	000903	000904	000908	000909	000932
	000933	000954	000993	000997	000999	001003	001005
	001013	001017	001021	001040	001052	001083	001084
	001103	001106	001110	001111	001114		

Hydrology	000004	000005	000009	000011	000013	000014	000017
	000020	000024	000026	000032	000033	000037	000039
	000041	000069	000075	000077	000078	000091	000097
	000102	000103	000109	000111	000115	000116	000121
	000123	000133	000134	000135	000140	000141	000145
	000146	000147	000148	000149	000152	000172	000175
	000180	000184	000193	000194	000195	000196	000197
	000198	000214	000216	000220	000236	000249	000254
	000261	000263	000274	000275	000285	000293	000296
	000300	000346	000410	000431	000439	000472	000491
	000506	000508	000552	000557	000611	000632	000637
	000655	000665	000678	000685	000695	000700	000713
	000718	000724	000740	000747	000751	000753	000758
	000767	000768	000769	000777	000779	000789	000812
	000850	000872	000880	000904	000928	000930	000950
	000978	000980	000986	000995	000999	001003	001017
	001018	001034	001043	001068	001079	001082	001084
	001093	001103	001107	001110	001114		
Industrial Waste	000024	000109	000508	000725	000850	000858	000861
	000862	000915	001032				
Infiltration	000073	000263	000632	000750			
Isotopes	000019	000069	000087	000276	000277	000631	000702
	000747	000768	000769	000777	000869	000871	000934
Lake Erie	000007	000030	000059	000080	000101	000118	000147
	000200	000228	000264	000488	000686	000722	000725
	000793	000807	000842	000923	000954	001029	001043
	001062	001079					
Lake Huron	000059	000080	000232	000817			
Lake Michigan	000001	000002	000014	000017	000050	000059	000074
	000075	000076	000080	000096	000103	000104	000108
	000111	000112	000113	000116	000122	000202	000212
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	000453	000494	000495	000507	000520	000723	000758
	000827	000829	000871	000912	000933	000935	001017
	001018	001019	001020				
Lake Ontario	000015	000094	000172	000200	000232	000337	000686
	000713	000714	000715	000740	000781	000824	000879
	001092	001093					
Lake Superior	000016	000028	000031	000032	000053	000081	000091
	000117	000176	000186	000187	000237	000285	000294
	000342	000484	000493	000529	000624	000633	000662
	000686	001094	001095	001099	001107		

Land Use	000001	000003	000012	000016	000021	000023	000033
	000065	000114	000118	000119	000134	000135	000136
	000137	000152	000156	000168	000170	000212	000213
	000244	000269	000285	000297	000299	000308	000310
	000329	000334	000370	000373	000417	000423	000425
	000426	000427	000436	000499	000519	000563	000611
	000620	000632	000633	000637	000674	000718	000729
	000753	000772	000799	000807	000848	000858	000891
	000941	000958	000961	000988	000989	000990	000991
	000992	000999	001029	001040	001045	001055	001056
Leachate	000008	000082	000224	000632	000720	000750	000850
	000925						
Legislation	000052	000182	000252	000290	000406	000407	000408
	000684	000758	000848	000957	000958	001052	
Liquid Waste	000008	000173	000425	000549	000695		
Map	000012	000035	000036	000038	000048	000063	000064
	000071	000138	000157	000158	000159	000160	000161
	000162	000163	000164	000165	000166	000167	000168
	000208	000226	000238	000250	000257	000266	000274
	000286	000287	000289	000297	000323	000324	000329
	000331	000332	000333	000341	000350	000353	000369
	000372	000373	000383	000398	000399	000400	000401
	000432	000433	000445	000446	000461	000488	000492
	000505	000530	000533	000535	000541	000542	000543
	000544	000545	000546	000547	000548	000579	000612
	000615	000625	000626	000627	000628	000633	000639
	000669	000694	000696	000697	000700	000703	000709
	000734	000735	000792	000799	000815	000835	000836
	000837	000838	000839	000842	000848	000854	000865
	000866	000867	000873	000874	000875	000876	000877
	000898	000926	000927	000943	000947	000948	000954
	000956	000977	000978	000980	000988	000989	000990
	000991	000992	001004	001022	001023	001024	001025
	001026	001027	001035	001039	001040	001054	001055
	001058	001059	001062	001070	001075	001076	001103
	001107	001108					
Metals	000188	000484	000661	000852	000869	000888	000924
	000946						
Mining	000134	000135	000137	000293	000630	000631	000658
	000827	001045					

Model	000013	000030	000034	000036	000054	000075	000092
	000102	000103	000105	000111	000113	000131	000145
	000150	000156	000223	000245	000249	000251	000252
	000255	000256	000272	000296	000334	000343	000344
	000345	000352	000364	000431	000481	000502	000509
	000510	000524	000525	000526	000658	000660	000691
	000705	000724	000728	000785	000818	000829	000850
	000884	000925	000930	000937	001003	001015	001019
	001109	001110					
Municipal Water	000005	000020	000024	000042	000082	000096	000106
	000134	000135	000136	000137	000211	000464	000536
	000841	000956	001019				
Natural Gas	000142	001064					
Nitrates	000022	000155	000467	000468	000674	000997	
Nonpoint Pollution	000016	000022	000023	000034	000052	000119	000120
	000425	000475	000519	000562	000791	001109	
Oil	000142	000367	000806	000924			
Organic Material	000088	000095	000123	000173	000174	000181	000219
	000284	000346	000373	000439	000462	000748	000843
	000844	000902	000907	000915			
Permeability	000110	000116	000221	000381	000764	000930	001040
Pesticides	000022	000519	000524	001029			
pH	000068	000220	000654	000655	000732	000944	000946
Phosphorus	000110	000791					
Photogeology	000039	000159	000160	000161	000162	000163	000164
	000165	000166	000167	000751			
Planning	000001	000003	000052	000065	000066	000067	000153
	000156	000170	000228	000254	000265	000297	000309
	000312	000353	000419	000420	000421	000422	000440
	000441	000453	000492	000504	000562	000610	000638
	000685	000723	000753	000827	000845	000848	000886
	000900	000938	000950	000957	000959	000962	000970
	000971	001001	001012	001014	001086		

Pollution	000006	000008	000013	000016	000021	000022	000023
	000029	000039	000046	000052	000054	000062	000065
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	000106	000118	000119	000121	000123	000142	000147
	000153	000156	000169	000173	000174	000178	000181
	000182	000189	000220	000241	000253	000303	000364
	000378	000406	000423	000425	000426	000427	000439
	000441	000468	000501	000508	000519	000524	000536
	000549	000557	000562	000630	000631	000665	000674
	000691	000701	000702	000718	000720	000725	000747
	000748	000750	000774	000775	000806	000818	000821
	000822	000823	000850	000851	000852	000861	000862
	000863	000864	000869	000872	000888	000902	000906
	000907	000911	000915	000924	000957	000966	000967
	000999	001032	001041	001043	001063	001109	
Porosity	000073	000909	000930				
Precipitation	000027	000062	000100	000145	000247	000359	000448
	000552	000700	000718	000724	000740	000750	000825
	000827	000884	000944	000946	001068	001093	
Pumpage	000020	000042	000113	000251	000464	000465	000496
	000525	000745	000816	000826	000904	001104	
Radioactive	000019	000253	000275	000277	000433	000701	000702
	000747	000760	000761	000762	000764	000765	000767
	000768	000769	000777	000849	000880	001005	
Recharge	000001	000033	000046	000061	000065	000073	000075
	000108	000111	000116	000180	000251	000378	000441
	000448	000642	000677	000739	000758	000762	000782
	000818	000827	000829	000847	000871	000888	001018
	001020	001052					
Reclamation	000065	000911	001045				
Remote Sensing	000012	000037	000039	000061	000067	000159	000160
	000161	000162	000163	000164	000165	000166	000167
	000269	000579	000704	000740	000781	000914	000922
	000936	001057					
Reservoirs	000090	000093	000113	000126	000252	000267	000325
	000326	000327	000328	000380	000456	000654	000655
	000659	000723	000829	000946	001057	001082	
Runoff	000068	000069	000081	000120	000145	000285	000453
	000541	000552	000700	000704	000725	000758	000823
	000882	000883	000954	001093			
Saline Water	000210	000755	000854				
Sand	000002	000263	000711	000826	000935		

Saturated Zone	000054						
Sediments	000002	000007	000028	000029	000030	000047	000053
	000059	000072	000077	000085	000094	000095	000101
	000103	000104	000110	000116	000117	000119	000122
	000123	000127	000128	000176	000186	000187	000201
	000203	000219	000229	000232	000233	000237	000248
	000259	000284	000302	000333	000352	000356	000367
	000438	000474	000477	000488	000493	000495	000503
	000507	000511	000512	000519	000531	000534	000553
	000554	000579	000600	000601	000614	000631	000633
	000634	000635	000636	000661	000673	000701	000702
	000722	000735	000748	000793	000794	000806	000824
	000842	000860	000869	000887	000912	000923	000924
	000930	000935	001043	001062	001071	001072	001073
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Shale	000352	000661	000714				
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	000805	000818	000870	000925	000999	001040	001055
	001064	001065	001103				
Solid Waste	000425	000440	000549	000719	000769	000777	000851
	000903						
Storativity	000253	000702	000788	000816			
Stratigraphy	000463	000636	000776	000820	000937	001061	
Structural Geology	000009	000014	000015	000035	000036	000038	000048
	000063	000074	000089	000138	000150	000157	000158
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	000202	000212	000238	000266	000286	000372	000639
	000682	000695	000697	000909	001095		
Sulfates	000276	000871					
Surface Water	000014	000020	000043	000068	000077	000091	000108
	000113	000116	000120	000124	000285	000366	000429
	000506	000754	000788	000826	001068		

Surficial Geology	000026	000046	000091	000109	000138	000193	000194
	000196	000437	000505	000553	000580	000581	000582
	000583	000584	000585	000586	000587	000588	000589
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	000643	000644	000645	000646	000647	000648	000649
	000650	000651	000652	000653	000700	000734	000789
	000879	000900	001075	001103			
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	001043						
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	001032	001041	001044	001077	001111		
Waste Water	000054	000082	000100	000121	000153	000173	000174
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	000364	000526	000538	000552	000611	000632	000672
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	000908	000909	000935	000937	000956	001017	001018
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	000092	000096	000097	000106	000118	000119	000123
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	000151	000153	000155	000156	000169	000171	000184
	000206	000210	000211	000218	000241	000250	000263
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	000344	000346	000349	000350	000351	000357	000362
	000371	000378	000405	000425	000441	000509	000511
	000519	000562	000620	000621	000665	000674	000677
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	000792	000821	000822	000829	000831	000851	000862
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	001106	001107					
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	000288	000292	000294	000307	000311	000347	000348
	000361	000363	000376	000377	000379	000396	000397
	000399	000411	000412	000470	000471	000489	000490
	000515	000550	000556	000568	000572	000573	000574
	000575	000596	000611	000613	000620	000659	000669
	000693	000694	000698	000699	000708	000714	000721
	000737	000738	000787	000804	000810	000811	000813
	000814	000826	000827	000833	000840	000868	000878
	000881	000916	000942	000955	000956	000965	001008
	001009	001011	001020	001034	001038	001045	001048
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Water Supply	000001	000004	000005	000017	000020	000022	000024
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	000081	000086	000096	000099	000109	000126	000130
	000133	000134	000135	000136	000137	000143	000149
	000177	000182	000183	000193	000194	000195	000196
	000197	000198	000206	000207	000252	000277	000279
	000281	000282	000291	000294	000306	000407	000408
	000413	000414	000415	000453	000497	000520	000536
	000559	000562	000611	000659	000816	000826	000827
	000849	000880	000917	000953	000954	000956	000959
	001014	001019	001020	001034	001114		
Water Use	000033	000042	000096	000100	000118	000145	000169
	000192	000252	000370	000465	000466	000480	000496
	000497	000516	000536	000562	000564	000565	000566
	000567	000569	000570	000571	000656	000657	000708
	000721	000826	000830	000889	000890	000894	000895
	000896	000953	000956	001034	001064		
Watershed	000021	000031	000062	000067	000069	000081	000145
	000170	000171	000216	000439	000607	000654	000700
	000718	000730	000754	000758	000780	000944	000945
	000967	000979	000981	000982	000983	000984	000985
	001018						
Well Data	000004	000026	000029	000049	000104	000349	000473
	000479	000671	000745	000908	000969	000997	001028
	001041	001044					
Well-Logging	000025	000035	000059	000232	000349	000701	000793
	000933						
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<u>Author</u>	<u>Reference number</u>
Ackermann, W.C.	000001
Acomb, L.J.	000002
Adams, J.R.	000829 000880
Alberta Environmental Coordination Service	000003
Allen, R.V.	000599
Allen, W.B.	000004 000005
Aller, Linda	000006
Anderhalt, R.	000007 000101
Anderson, D.H.	000628
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Anderson, K.E.	000012 000244
Anderson, L.E.	000752
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Andrews, S.C.	000016
Angelo, C.G.	000079
Archer, R.J.	000488
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Baadsgaard, H.	000286
Bach, W.N.	000891
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Baker, D.B.	000021 000022 000023
Balaban, N.H.	000623 000921
Banaszak, K.J.	000024 000146 001049
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Barnett, P.J.	000030
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Martin, Angel, Jr.	000410			
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Schneider, W.J.	000027 000840 000841
Schock, S.C.	000692
Schooler, E.E.	000842
Schornick, J.C., Jr.	000490
Schroeder, R.A.	000843 000844
Schultink, Gerhardus	000845 000846
Schultz, G.K.	000326
Schultz, M.G.	000847
Schulz, K.J.	000324
Schwartz, G.M.	000035 000036
Schwing, Eric	000846
Scieszka, Michael	000226 000848
Scott, R.C.	000849

Scrudato, R.J.	000850 000851 000852
Sedam, A.C.	000079 000853 000854
Sehraufnagel, F.H.	000855
Sellman, B.N.	000329
Shafer, J.M.	000086 000856
Shampine, W.J.	000556
Shaver, R.H.	000202 000203
Sheaffer, J.R.	000857
Shear, H.	000858
Shedlock, R.J.	000024 000125 000146 000859 000860 001049
Shepps, V.C.	000939
Sherrill, M.G.	000265 000671 000861 000862 000863 000864 000865 000866 000867 001021
Shindel, H.L.	000868
Sibley, D.F.	000869
Siegel, D.I.	000870 000871 000872 001106
Simmons, M.S.	000687
Simon, J.A.	001072
Sims, P.K.	000627 000696 000697 000873 000874 000875 000876 000877
Simsiman, G.V.	000120
Sinclair, W.C.	000878
Singer, S.	000879
Singh, K.P.	000880
Skinner, E.L.	000132 000283 000881 001066 001107
Sklash, M.G.	000882 000883 000884
Sly, P.G.	000885
Smith, H.F.	000886
Smith, P.A.	000887
Smith, S.A.	000065
Smyth, D.J.	000888
Snavely, D.S.	000451 000844 000889
Solley, W.B.	000890
Sonzogni, W.C.	000479 000629 000891 000892 000893
Southeastern Wisconsin Regional Planning Commission	000894 000895 000896
Southwick, D.L.	000627 000876
Southwood, R.J.	000897
Sparks, D.M.	000545 000546 000547
Sparling, D.R.	000898
Stadnyk, Lelyn	000285
Stall, J.B.	000829
Stanley, R.J.	000899

Stark, J.R.	000347	000900	000901	000902
Starkey, M.J.	000903			
Staubitz, W.W.	000605	000621	000904	
Stayton, D.S.	000509			
Stein, R.B.	000854	000905		
Steinhart, C.E.	000831	000906	000907	
Stelz, W.G.	000009	000010	000600	000606 001040
Stephenson, D.A.	000065	000204	000908	
Sterrett, R.J.	000909			
Stewart, J.A.	000146			
Stieglitz, R.D.	001065			
Stith, D.A.	000910			
Stoermer, E.F.	000911			
Stoffel, K.L.	000205	000912		
Stoimenoff, L.E.	000281	000283		
Stollar, R.L.	000913	001005		
Stone, W.D.	000462			
Stortz, K.R.	000914	000922		
Strachan, W.M.	000088	000284	000915	
Straw, W.T.	000720			
Student, J.D.	000745	000916	001091	
Sturgis, D.S.	000007	000101		
Summers, W.K.	000917			
Swain, L.A.	000918	000919		
Swain, W.R.	000521	000522	000893	000922
Swanson, L.	000623	000920	000921	
Sydor, Michael	000187	000704	000705	000914 000922
Szabo, J.P.	000923			
Taft, C.E.	000924			
Tanner, C.B.	000925			
Taylor, R.B.	000926	000927		
Taylor, R.W.	000014	000077	000114	000115 000928 000929
	000930			
Taylor, S.R.	000931			
Terry, D.B.	000716	000932		
Thomann, R.V.	000691			
Thomas, J.A.	000533			
Thomas, R.L.	000259	000458	000885	
Thompson, D.B.	000933			
Thompson, M.E.	000934			
Thompson, M.J.	000381			
Thompson, T.A.	000935			
Tilmann, S.E.	000936			
Timmermans, T.J.	000937			
Timms, Arthur	000938			
Tkacz, R.J.	000748			

Tomikel, J.C.	000939
Tomlinson, R.F.	000940 000941
Totten, S.M.	001061 001062
Trainer, F.W.	000942
Treese, T.	000817
Trotta, L.C.	000350 000943
Troutman, D.E.	000944 000945 000946
Tucci, P.	000557
Turk, J.T.	001041
Twenter, F.R.	000152 000294 000295 000348 000471 000472 000901 000947 000948 000949 000950 000951 000952 000953 000954 000955
Tychsen, P.C.	000186
U.S. Army Corps of Engineers	000956
U.S. Congress House Subcommittee on Natural Resources and Environment	000957
U.S. Congress, Senate Subcommittee on Parks, Recreation, and Renewable Resources	000958
U.S. Department of Agriculture	000959
U.S. Department of Commerce	000960 000961
U.S. Department of Housing and Urban Development	000962
U.S. Department of the Interior	000963 000964 000965
U.S. Environmental Protection Agency	000966 000967 000968 000969 000970 000971 000972 000973 000974 000975 000976
U.S. Environmental Protection Agency and Environment Canada	000977
U.S. Geological Survey	000978 000979 000980 000981 000982 000983 000984 000985 000986 000987 000988 000989 000990 000991 000992 000993 000994 000995 000996 000997
U.S. Office of Water Resources Research	000998
U.S. Soil Conservation Service	000999
University of Michigan	001000
University of Wisconsin	001001
Upchurch, S.B.	000121 000123 001002
Urie, D.H.	000082
Urish, D.W.	001003
Vallejo, L.E.	000213
Van Alstine, J.L.	000198

Van Demark, P.	001004
Van Der Leeden, F.	001005
Van Rooyen, D.J.	000072
Van Til, R.L.	000043
Vanlier, K.E.	000183 000184 001006 001007 001008 001009 001010 001011 001012 001013 001014 001067
Varaksin, S.	000711
Venzke, C.P.	001015
Verry, E.S.	000062
Vidra, A.C.	000297
Vincent, James	001016
Visocky, A.P.	001017 001018 001019 001020 001021
Viswanathan, S.	000877 001022 001023 001024 001025 001026 001027
Vitosh, M.L.	000033
Vivyurka, A.J.	000631
Voelker, D.C.	001028
Von Boehm, B.	000857
Vopelak, P.A.	000326
Wagner, T.W.	000781
Waldron, A.C.	001029
Walker, A.C.	001030 001031
Wallace, B.	001032
Wallace, J.C.	000185
Waller, J.	001033
Waller, R.M.	001034 001035 001036 001037 001038 001039 001040 001041
Waller, Robert	001042
Walters, L.J., Jr.	001043
Ward, P.E.	001048
Warner, D.L.	001044
Warner, F.K.	001045
Warrick, R.E.	001046
Warry, N.D.	000715
Water Resources Scientific Information Center	001047
Watkins, F.A., Jr.	001048
Watroba, D.A.	000029
Watson, L.R.	000024 001049
Weeks, A.D.	000431
Wehde, M.E.	000216 001055
Weiblen, P.W.	000323 000628
Weimer, L.	001050
Weininger, D.	001051

Weist, W.G., Jr.	000452 001052 001053
Welkie, C.	000661
Wentz, D.A.	000132
Western Michigan University	001054
Westin, F.C.	001055
Wezernak, C.T.	000067 001056
Wheeler, M.L.	001013
Whetstone, G.E.	000281
Whipple, J.M.	001057
Whisnant, David	000285
Whistler, Jerry	001063
White, G.W.	001058 001059 001060 001061 001062 001080
Whittemore, D.O.	001063
Whittmann, S.G.	001064
Wiersma, J.H.	000823 001065
Wiitala, S.W.	001066 001067 000782
Wilder, S.V.	001068
Wilkinson, B.W.	000869
Williams, A.S.	001069
Williams, G.E.	000327 000328
Williams, J.D.H.	000458
Willman, H.B.	001070 001071 001072 001073 001074 001075
	001076
Wilson, C.D.	000016
Wilson, R.	001033
Wiltshire, D.A.	001077 001078
Winegardner, D.L.	001079
Winslow, J.D.	001046 001080
Winter, T.C.	000138 001081 001082 001083 001084
Winters, H.A.	000795
Wisconsin Committee on Water Pollution	001085
Wisconsin Department of Natural Resources	001086 001087 001088 001089 001090
Wisconsin Geological and Natural History Survey	001090
Withers, L.J.	000745 001091
Witherspoon, D.F.	001092 001093
Wold, R.J.	001094 001095 001096
Wolfert, M.F.	001097
Wood, W.W.	000005 001014
Woolridge, B.A.	000297
Wright, H.E., Jr.	000533 001098 001099
Wu, Tien Hsing	001100

Wyrick, G.G.	001101
Yager, R.M.	001102 001103
Yanggen, D.A.	000803
Young, H.L.	000134 000135 000136 000137 000138 000671 001104 001105 001106 001107
Young, R.A.	001108 001109
Zager, J.P.	001110
Zajd, H.J., Jr.	000377
Zaporozec, Alexander	001111 001112
Zarriello, P.J.	001103
Zarth, R.J.	000634
Ziarno, J.A.	000106
Zumberge, J.H.	001113
Zvibleman, B.	000116
Zwilling, D.	001114